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Understanding Impact of Technology Interventions in Indian Engineering Education

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Abstract This paper uses the coupled functional-structural analysis to understand and compare the use of two technologies, namely satellites and internet, in engineering education in India. The case studies clearly point out that any policy intervention that aims to use technology for better delivery of services should keep in focus the capabilities of all the actors involved, as well as strive for organisational arrangements and mechanisms that takes the opportunities and incentives of these actors into consideration. Access statistics show that technology intervention that follows this guideline is relatively more successful. We also argue that success of technology interventions in education should be measured in terms of its reach.

Keywords Engineering education, Technology, Satellite, Webcast, Innovation Systems, Functional-Structural Analysis.

JEL Classification I23, O33, O35

1. Background

Education has been one of the areas where technology has been used to achieve numerous objectives. Since the early 1970s, India has made various efforts at utilising satellites for promoting access to education

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(Bhaskaranarayana et al. 2009), which includes engineering education. In the Indian case, there are a number of issues that have plagued the system of engineering education. The key issue is the lack of qualified faculty. In the thousands of engineering colleges of the country, inexperienced and undergraduate degree holders are appointed as lecturers, which feeds to the gap between the desired level and the current level of expertise available among the faculty. A majority of these fresh engineers who have been trained by this combination of lack of quality faculty and subpar private engineering colleges have already been labelled as “unemployable” by the current major employer, the Indian software industry. This problem has been recognized by the Government of India and there are steps that are being taken not only by the concerned department but also by the Indian Space Research Organization (ISRO) and the chain of Indian Institutes of Technology[1] (IITs). In September 2004, ISRO launched an educational satellite *EduSat*, built exclusively for serving the educational sector. Institutes like the IIT Bombay, have used EduSat to enhance their distance education programme.

During the same time, the IITs and the Indian Institute of Science (IISc) came together to put forward a proposal to the Government of India’s Ministry of Human Resource Development (MHRD) to create content for 100 courses as web-based supplements to be distributed through the Internet. Thus, the National Programme on Technology Enhanced Learning (NPTEL) initiative was born. It created complete, free and open online courseware for engineering, science and management subjects. The contents of *NPTEL* are available free to everyone in the world and follow closely the curriculum design adopted by major technical universities in India.

As one would expect, the impact[2] of these efforts of using technology in engineering education, in terms of reach and utilization, have not been the same. This experiment of using two different technologies in engineering education provides us an opportunity to fine tune our tools of understanding or measuring technological change. The contribution of this paper is that it tries to understand this experience of the application of the two different technologies[3] in engineering education using the coupled

[1] The tiny elite sector in the system the Indian Institutes of Technology (IIT) at the national level and a group of prestigious institutions at the State level, seem to be less affected by this quality gap. Rest of the sector, most of which are privately run engineering colleges, has been responsible for the rapid growth in engineering education and hence educate a vast majority of Indian engineers (Walsh 2011).

[2] When we say impact, we imply only the reach of the effort and how many users have been and continue to access the effort.

[3] EduSat was used for live-transmission-based synchronous education; while

functional-structural (Wieczorek and Hekkert 2012) analysis developed for innovation systems. We then use the analysis to suggest inferences for innovation systems in the field of education.

The paper is organised as follows, in the next section we briefly explain EduSat and *NPTEL* followed by a section on the functional and structural analysis framework. Section 4 then analyzes the EduSat and NPTEL interventions in engineering education using the coupled functional-structural analysis framework. The paper makes its concluding observations in section 5.

2. Educational satellite *EduSat* and the National Programme on Technology Enhanced Learning (NPTEL)

EduSat, launched on 20 September 2004, was mainly intended to meet the demand for an interactive satellite-based distance education system for the country. This satellite was specially configured for audio-visual medium, employing digital interactive classroom and multimedia multi-centric system. The satellite had numerous technological possibilities for broadcast as well as return links; for example, broadcast was possible through radio, television, and internet. Similarly, webcam, telephone, talkback channel, and internet medium could be used as return link. With respect to EduSat, ISRO spearheaded access to this technology by setting up broadcast and receiving terminals. Figure 1 gives the various possibilities of EduSat.

ISRO conceived the EduSat project in October 2002. Before the launch of EduSat, ISRO initiated discussions and deliberations at a national level to give direction to the "EduSat Utilization Programme." A series of consultations, seminars, and workshops were organized; all the stakeholders who were participants in these seminars were familiarized with the concept, technology, applications and proposed process of implementation, and issues in terms of operations and management of the network and utilization. Discussions were also held on a variety of issues including the subjects that could be taken up for teaching, interactivity, and quality of content etc. ISRO then set up appropriate project-structure to monitor, supervise, and formulate the policies and guidelines to run this programme. ISRO implemented the *EduSat Utilization Programme* in three phases: pilot, semi-operational, and operational. In the pilot phase,

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NPTEL uses recorded video, which is an example of asynchronous education. I thank an anonymous referee and Prof. Siddharthan for pointing this out in an earlier version of this paper.

which was before the launch of EduSat, engineering colleges of three universities in India were connected through three independent networks using Indian National Satellite System (INSAT) 3B Ku-band transponder (Bhaskaranarayana et al 2009). To make optimum use of EduSat capabilities, ISRO also reviewed its pilot phase through a research institute.

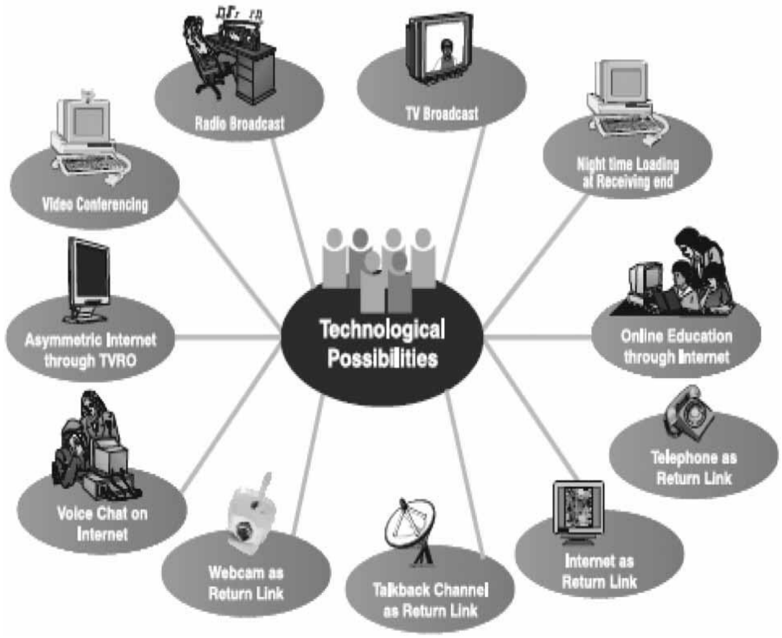

Figure 1: Uses of EduSat (Source: ISRO brochure on EduSat. Accessed August 22, 2011. http://www.isro.org/publications/pdf/Edusat-Brochure.pdf.)

The NPTEL programme began in 2003, with an aim of creating 120 internet based course supplements, 115 video courses and encapsulation/ conversion of existing 110 video courses. Supplementary learning materials for 40 hours was planned in each course; video courses were to contain 40 one-hour lectures per course for telecast through *Eklavya* television channel. Formally launched in September 2006, more than 80 per cent content in NPTEL has been designed and developed for dissemination through the web. Video lectures are being broadcasted through the Eklavya channel, and approximately 50 engineering institutions across India have set up receivers to receive signal in their campuses. Thus, NPTEL is a curriculum development exercise in electronic form whose material could also be used as “reference” for students.

In phase one, each of the eight partner institutions identified individual faculty members to represent their institutions in a National group, responsible for management of content development process; at the institute level faculty members in each discipline were identified as discipline coordinators. The institutes also distributed work to identified subject matter experts, with minimum duplication. Feedback during intermediate stages of content development was collected through workshops for user faculty from representative colleges in each region. Efforts were taken to create suitable IT support infrastructure and software. Finally, a distribution mechanism in the form of CD ROMs/DVDs, was put in place for institutions that lacked internet connectivity. The second and third phase was from 2007-2012. Major project deliverables here include conversion of NPTEL phase I video courses in streaming video lecture format, creation of additional 600 web and video courses in all major branches of engineering, physical sciences at the undergraduate and postgraduate levels, and management courses at the postgraduate level.

3. Structures and functions of innovations systems

The “Technology Specific Innovation System” (TSIS) has been defined by Carlsson and Stanckiewicz (1991) as a dynamic network of agents interacting in a specific economic area under a particular institutional infrastructure and involved in the generation, diffusion and utilisation of technology.

To unlock and displace an existing system, it is important that several TSIS develop successfully and take over part of the existing system. The determining factors for a TSIS can be traced by identifying all those activities that influence the development, diffusion and use of an innovation. These activities are also called “Functions of Innovation Systems;” Hekkert et al. (2007) have proposed the following seven functions: Entrepreneurial activities (F1), Knowledge development (F2), Knowledge diffusion through networks (F3), Guidance of the search (F4), Market formation (F5), Resources mobilization (F6), and Creation of legitimacy/counteract resistance to change (F7). It must be mentioned that these functions influence each other; fulfilment of a certain function quite likely has its effects on the fulfilment of other functions, thus leading to interactions among functions. New developments often start with a limited number of functions that often pull other system functions and the innovation system gains strength. Iyer (2017) uses the functions of innovation systems (FIS) to look at impact of NPTEL and EduSat in Indian Engineering education.

Wieczorek and Hekkert (2012) argue that this functional analysis needs to be coupled with a structural analysis for a better understanding of innovation systems. There are four structural elements of any TSIS: (a) actors, (b) institutions, (c) interactions, operating within (d) a specific infrastructure. Each of the functional element comprises all the structural elements within it. Thus, each function needs to be examined through the perspective of the four structural elements of the function. With respect to each function, the problems for actors can be presence related or capabilities related; institutional problems (both hard and soft) can be presence or capacity related; interaction problems can be presence or quality related, infrastructure problems can be presence or quality related.

Hekkert and Negro (2009) point out that the method used to map interaction patterns between system functions is inspired by "Historical Event Analysis." The goal of an event history analysis (EHA) is to explain a qualitative change (an "event") that occurs in the behaviour of a unit (can be an individual or any collective) at a particular point in time (Berry and Berry 1990). This approach consists of retrieving as many events as possible that have taken place in the innovation system using archive data, such as newspapers, magazines, reports, and articles from professional journals. The events are classified into event categories, and then allocated to a system function. The contribution of an event to the fulfilment of a system function may differ considerably from event to event. Some events have a positive contribution to the diffusion of the technology, while others may contribute negatively. The balance between positive and negative events yields specific insights on the analysed technology. Since the importance of an event is not known beforehand, it is not weighted in this methodology. In this paper we use the coupled functional-structural analysis (which in our opinion is a better framework compared to FIS) to understand the impact of NPTEL and EduSat in Indian Engineering

4. Case studies on use of technology in engineering education

We now present the description of the IIT Bombay distance education network from Iyer (2014) followed by a coupled functional-structural analysis of the network; analysis of the NPTEL programme is also done on similar lines.

4.1 Case study 1: Indian Institute of Technology, Bombay EduSat network

Moudgalya et al. (2009) state that ISRO was looking for live transmission of courses for EduSat, which opened the possibility of IIT Bombay collaborating with ISRO. When IIT Bombay switched over to EduSat, there were about 40 remote centres (with free of cost equipment given by ISRO) that could receive their transmission. Moudgalya et al. (2009) note the total number of remote centres including those in the pipeline there were about 90. New remote centres paid a onetime charge of about INR 500,000 for the infrastructure. Transmission through EduSat was preferable as it offered a guaranteed and reliable bandwidth at no cost for IIT Bombay. When IIT Bombay signed up with ISRO, different national dailies covered the event and students from all over the country wrote mails enquiring when a remote centre would be established in their town. However, ISRO generated invoices only after a minimum number of applications were received; as a result, it used to take anywhere between two to six months to establish a remote centre. Moudgalya et al. (2009) also note that while utilising EduSat, IIT Bombay was hampered by the lack of two essential infrastructure facilities; first, it did not have a receiving station, second, the hub was located at Amrita University in South India and not at IIT Bombay, which resulted in additional coordination difficulties. Ensuring that every remote centre was in working condition also required a lot of work and coordination with the service provider (Bharat Electronics Limited); as a result, many remote centres went inactive. Moudgalya (T4E'09 2009) presentation states that out of the 65 remote centres only 25 were active in 2009.

The growing demand for its courses across the country made IIT Bombay realize that it had to cater to the demand at a reasonable speed. However, given the challenges faced with respect to the time required to establish a remote centre, the coordination effort to keep it active, and the fact that IIT Bombay had only one channel on EduSat and was already fully using it; IIT Bombay concluded that it could not handle the demand for its courses across India using only EduSat. This compelled IIT Bombay to explore the possibility of using other technologies including webcast.

4.2 A Coupled Functional and Structural Analysis

With respect to functions, the main guiding factor (F4) for IIT Bombay and ISRO to initiate satellite transmission for distance education was responsibility towards society. This inspired both of these institutions to start their entrepreneurial activities (F1), collaborate with each other (F1) and use their resources (F6) towards the objective. The coverage by the media increased visibility and demand, resulting in the increase of the market size (F5). For the generated positive momentum to be sustained and the TSIS to be successful, one can identify at least three necessary conditions. First, infrastructure be rolled out before the enthusiasm for the technology reduces. Second, there be as little as co-ordination problems in the TSIS, this is for both the phases i.e. the setup of infrastructure as well as actual transmission. Finally, a better technology does not challenge or substitute this technology. Given the nature of users (primarily engineering students completing a four-year course) it was imperative that the first two conditions be met as soon as possible, or else users could embrace an alternative technology, which is available and accessible. The intensity of the actual events in this system led to an initial increase in the network size (F5), though not to the level of the demand that was generated. The routines followed by ISRO ensured that physical infrastructure required to cater to the actual demand lagged way behind. There was mismatch between the demand generated and the capability of the network to expand. ISRO also did not optimize the available resources on EduSat such that IIT Bombay had more bandwidth to increase its transmission. There were coordination problems at two levels; first, coordination with the receiving hub at south India; and, second, coordination with the service provider to ensure that all the remote centres were working. Finally, a new technology i.e. webcast entered the scene, webcast could cater to the huge demand with lesser resources, and offered more flexibility with respect to the user; thus, webcast challenged the IIT Bombay EduSat network.

Table 1 (below) captures the coupled functional-structural analysis of the IIT Bombay-EduSat network. Here, systemic problems are those factors that hinder the development and functioning of innovation systems. Our analysis points out that the IIT Bombay-EduSat network encountered systemic problems in the sixth and seventh system functions. The system lacked the resources and did not optimize available resources (-ve F6) to cater to the huge spurt in demand in such a short time, termed as Actors problems with respect to their capability and Institutions problems (capacity). This accentuated the coordination problems that arose in the IIT Bombay EduSat network (-ve F6); we interpret this as Interaction problems (intensity/quality). The slow roll out of physical infrastructure did not help in creating legitimacy, we interpret this as Infrastructure problems (capacity). An easily accessible technology i.e. webcast also entered the scene, which challenged legitimacy of EduSat technology (-ve F7). The advantage of webcast was that the lecture could be hosted at a website, which could be later accessed by a student at her/his convenience. As a result, in order to reach out to more towns/cities[4] in the country, IIT Bombay started using webcast in addition to using EduSat for the established remote centres. The impact of these systemic problems on the positive momentum of the system can be understood from the fact that out of the 65 remote centres in the network only 25 were active in 2009 (i.e.,

[4] Demand primarily came from towns/cities in the country rather than villages/country side.

around 38 per cent) reducing the growth as well as impact of the IIT Bombay EduSat TSIS.

System Function	Structural element	Systemic problem	Type of systemic problem
F1-entrepre-neurial activities	a) Actors: IIT Bombay, ISRO, Remote Centres, Media, Students, Service Providers b) Institutions: ISRO's routines, Expectations of students c) Interactions: IIT Bombay-ISRO, IIT Bombay-Remote Centres, IIT Bombay-Service Providers, IIT Bombay-Students d) Infrastructure: Physical, Financial	--	--
F2-knowledge development		--	--
F3-knowledge diffusion		--	--
F4-guidance of the search		--	--
F5-market formation		--	--
F6-mobilisation of resources		a)Actors problems b)Institutions problems c)Interactions problems d)Infrastructure problems	a) Capabilities b) Capacities c) Intensity/quality d) Capacity
F7-creation of legitimacy		d)Infrastructure problems	d) Capacity

Table 1: Functional-Structural Analysis of the IIT Bombay-EduSat network

4.3 Case study 2: NPTEL

According to Walsh (2011) the most striking feature of NPTEL is its consortial structure, as the eight partner institutions of NPTEL compete with each other for faculty and students. It also required all partner institutions to build consensus on fundamental curricular issues. The scope of NPTEL effort is significant as almost 350 faculty were involved in creating content for NPTEL; and the coordination of this faculty effort itself has been a successful experiment in cooperation. This has resulted in a great deal of content. The NPTEL team's only marketing were probably the mailings on NPTEL that were sent to about 2,200 Indian colleges on two different occasions. Though the awareness of the initiative was not as widespread as the NPTEL team desired; the site attracted its users with minimal outreach and very little marketing. He also notes that NPTEL received over 100,000 visitors per month in the fall of 2008, with video courses being more popular than web courses.

Ravi and Jani (2011) point out that promotion of NPTEL was done using many different methods. Posters and brochures were sent by mail to more than 3,500 institutes across the country. Emails and bulk short messaging services were also sent to principals and placement officers of various colleges across the country. A marketing team visited nearly 350 engineering colleges across the country. This was supplemented with online competitions and the selection of student ambassadors across different campuses. They also note as of March 2010, students (47 per cent of total users) and faculty (10 per cent) from 93 universities, and working professionals (43 per cent) from 175 companies were using NPTEL.

Period	Videos	Channel Views
Jan-Dec, 2008	3198	6,939,361
Jan-Dec, 2009	3965	11,898,397
Jan-Dec, 2010	4618	20,273,740
Jan-Dec, 2011	6400	29,291,453
Jan-Dec, 2012	10,563	39,482,461
Jan-Dec, 2013	90,480	53,541,773
Jan-June, 2014	92,356	33,177,780

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Table 2: NPTEL-YouTube statistics (Source: Presentation 'NME–ICT', by Pradeep Kaul, at "One Agriculture-One Science", Telangana, 9th March 2015)

A study by Sarvanan and Esmail (2014) looks at the availability and impact of NPTEL in seven selected engineering colleges (among 33) in *Thiruvallur* district in the state of Tamil Nadu. This study which analysed 300 survey questionnaires found that 223 respondents accessed NPTEL from the library, 32 from computer lab and college hostel, 28 through browsing centres, and 17 from their home. Access to NPTEL for engineering students and faculty had to be shared, which limited the time an individual can spend benefitting from NPTEL. As of 14th July 2015, according to the NPTEL website, officially there were 982 engineering institutions across the country, which were using NPTEL.

Table 2 shows the NPTEL-YouTube statistics for comparable periods of time; we assume that video hours are cumulative over the years while channel views are the views for that particular period. It is interesting to note that from 2008 to 2013 while video hours have increased by a factor of almost 30, the channel views at the maximum has increased by a factor of nine. If one analyses the numbers in table 2 by channel view per video hour per day, then it shows an interesting pattern (Chart 1).

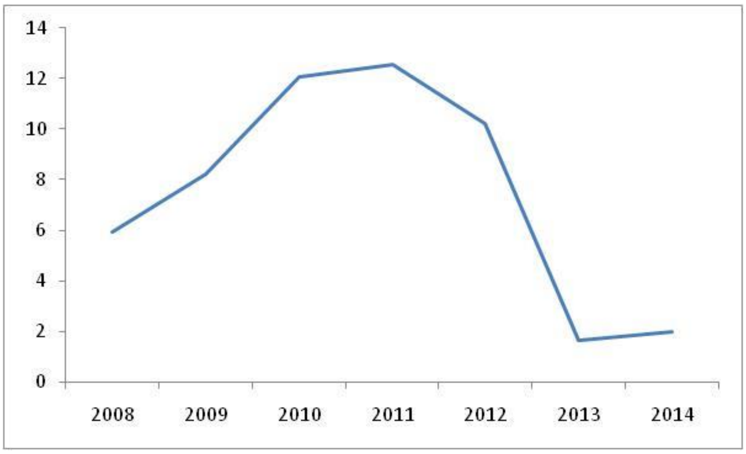

Chart 1: Trend of views per video per day (Data source: Data presented in Table 2.)

The trend was of increase from 2008 till 2011, with a slight decline in 2012 when the video hours increased from 6,400 to 10,563. There is a drastic drop in the year 2013 when the video hours increased from 10,563 to 90,480. It could also be possible that users are now accessing this content through other means, for example, through the Ekalavya television channel which also beams these lectures, or users may have downloaded the lectures which may have brought down the view per video per day. It must also be mentioned that the time spent[5] by each user on NPTEL-You

[5] I want to thank an anonymous referee for pointing this out in an earlier version of this paper.

Tube or on the videos is an important parameter, to better understand the reach of NPTEL. Since, we do not have those numbers at this point of time we are unable to comment on them. As can be seen from the chart, the trend has shown an increase in the first half of 2014.

What emerges out of this whole exercise is the fact that NPTEL has been able to reach out to larger audience. Chart 2 testifies this statement, 27.83 per cent of the users of NPTEL are not from India. It has users from the United States, United Kingdom, Canada, Germany, Pakistan, Egypt, Singapore, United Arab Emirates, Saudi Arabia, and other countries. It is quite possible that the Indian Diaspora in these countries may be accessing NPTEL.

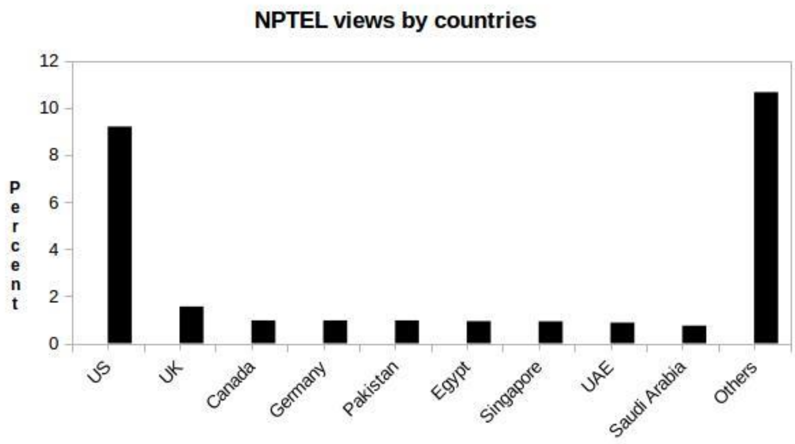

Chart 2: NPTEL user profile outside India (Source: Presentation 'NME–ICT', by Pradeep Kaul, at "One Agriculture- One Science", Telangana, 9th March 2015)

The press coverage of this initiative has been extremely positive and has increased its reach. Table 3 presents a indicative snapshot. Most of the articles listed are positive stories about online learning & NPTEL, and given the growing internet diffusion in India, probably would have helped the cause of NPTEL by generating further interest.

Date	Article	Paper
Nov 27, 2007	NPTEL set for second phase	The Hindu
Dec 08 2007	Thanks, but we don't need your courses: IITs tell MIT	The Indian Express
July 28, 2008	IIT online learning courses gaining momentum	The Hindu
Mar 09, 2009	NPTEL - streaming knowledge to all	The Hindu
May 29, 2011	OpenStudy to forge partnership with NPTEL	The Hindu
Nov 01, 2012	Studying at IITs just a click away, online courses soon	Hindustan Times
Sep 21, 2013	IITs, IISc to take engineering to rural areas	Deccan Chronicle
Dec 17, 2014	NPTEL announces 11 new online courses	The Tribune
Mar 19, 2015	How NPTEL democratising education and going into the next level	The Economic Times
May 17, 2015	NPTEL – waiting to become a hit among students	The Hindu

Table 3: Snapshot of Press coverage for NPTEL

Walsh (2011) mentions NPTEL's leadership did not consider offering credit or certification to users due to concerns about maintaining the academic standards of the IITs'. The interest that NPTEL generated led it to revisit certification. In March 2014, an online certification course was started by IIT Madras through NPTEL, after which, 1150 certificates were awarded to successful candidates of the first massive online certification course (MOOC) on "Programming, Data Structures and Algorithms." As a part of MOOC, proctored exams were held at 10 cities across India. From the Indian industry, National Association of Software and Service Companies (NASSCOM) collaborated with NPTEL for this effort.

As one of the press coverage in table 3 mentions, after the success of the first MOOC, NPTEL has introduced 11 new online certification courses (NOC). This press note explains that NOC ensures student involvement and continued participation during the running of the online course. This is followed by a proctored certification exam with e-verifiable scores that attests the learning of the student and adds value to the resume (because of the IIT and NASSCOM brand) in the job market. Physical certificates will be awarded to successful candidates, whose digital versions along with the student scores can be verified online by prospective employers. The enrolment for these courses is free. In view of the overwhelming response, the number of cities in India where exams would be held has been increased from 10 to 100.

4.4 A Coupled functional and structural analysis of system

The goal of NPTEL was to make content available to the largest number of students and engineering aspirants in the country. This was the guidance factor (F4) to unleash their entrepreneurial energy (F1). We think that prior experience of one of the partner institutions (F2 and F3) helped NPTEL to choose webcast as the technology to reach out a wider audience. The growth and use of internet in India in the past decade has increased exponentially, which had its own positive momentum. Thus, the choice of webcast by NPTEL to launch their content added to the positive momentum of the initiative (F5). MHRD (F6) contributed with financial resources while the partner institutions pooled in the human resources (F6). The amount of coordination and cooperation among the partner institutions (F6) in pursuit of a single goal kept the positive momentum going. In phase two and three there were efforts towards marketing of the project (F5). In phase two, with increased funding from MHRD (F6), the efforts of the NPTEL team towards industry-interfaces and certification courses (F6), as well as the increased press coverage resulted in increased views and subscribers not only in India but across the world (F5). The fact that the target group of students, working professionals, and faculty (to a lesser extent) accessed the content[6] implies that NPTEL was able to reach out to its core audience. The tremendous response to MOOC, due to the brand name of the partner institutions & NASSCOM, and the choice of certification courses that were offered; also, stands testimony to the impact of NPTEL (F5) and the positive momentum gained by the effort. Thus, many of the functions in this innovation system have been reinforced each other increasing the impact.

However, there are few challenges that are not allowing NPTEL to realise its true potential, for example, in one of the studies above it can be seen that most of the students' access NPTEL only through the library with very few accessing from their home (-ve F6). This is also reflected in some sense in the drastic drop of views per video per day for the years 2013 and 2014. There is also the other social issue of faculty (-ve F7) in other engineering colleges not wanting to use NPTEL (as it may show them in a bad/inferior light). Currently the huge demand for quality content coupled with the incentive to be associated with the brand name of IITs and IISc (elite institutions) - both of which are important from the perspective of getting a job for thousands of engineering students in India - make these negative issues extremely minor not to affect the positive momentum of the

[6] See Mangala (2012).

TSIS. However, these negative issues are surely impeding the growth/ potential reach of NPTEL.

The functional-structural analysis of NPTEL can be found in table 4. In NPTEL the partner institutions after coordination, record and load the content on an established content distribution platform (internet or YouTube), which better suits their capability; also, the large-scale diffusion of internet helped the network to reach a large number of users, who have access the recorded lectures at their convenience. As in the IIT Bombay-EduSat network, it can be seen that there are no systemic problems in the first five system functions; problems arise only in the sixth and seventh function. The problems of NPTEL come at the Actor level (related to their capability/capacity), as most of the students' access NPTEL only through the library with very few accessing from their home. Private colleges, which are also important Actors in this TSIS are unable to provide enough access points for their students to NPTEL (capability/capacity problem). Then there is also the social issue of faculty in other engineering colleges not wanting to use NPTEL. This creates systemic capability problems at the Actor level which hinders in the creation of legitimacy for NPTEL.

System Function	**Structural element**	**Systemic problem**	**Type of systemic problem**
F1-entrepreneurial activities	a) Actors: IITs and IISc, Government, Media, Students, Service Providers, Faculty and management of other engineering colleges b) Institutions: IITs and IISc routines, Government routines, Expectations of students c) Interactions: IITs and IISc, IITs & IISc and Government, IITs & IISc and Service Providers, IITs & IISc and Students, IITs & IISc and Faculty of other colleges d) Infrastructure: Physical, Financial	--	--
F2-knowledge development		--	--
F3-knowledge diffusion		--	--
F4-guidance of the search		--	--
F5-market formation		--	--
F6-mobilisation of resources		a)Actor problems	a) Capability
F7-creation of legitimacy		a)Actor problems	a) Capability

Table 4: Functional-Structural Analysis of NPTEL

A comparison of table 1 and table 4 shows that NPTEL has fared better than the satellite network, in the sense that it had lesser systemic problems in the innovation system than the satellite network. The better performance of NPTEL points out to the fact that NPTEL has been able to manage more sucessfully the process of technological change. Dosi (1997) points out that four objects of analysis help us understand technological change - changes in innovative opportunities; incentives to exploit the innovative opportunities; capabilities of the agents to achieve whatever they try to do, conditional on their perceptions of both opportunities and incentives; organisational arrangements and mechanisms through which technological advance is implemented.

The striking difference between NPTEL and EduSat comes in the third and fourth factor. In NPTEL, each of the partner institutions recorded and loaded the content on an established content distribution platform (internet or YouTube), which better suited their capability than the work in EduSat network. EduSat network involved live transmission of the content or a virtual classroom; this implied that work here included coordinating and working with two other organizations, for the content to be beamed and ensure that all systems in the remote centres were in working condition so that a real time virtual classroom was created. We have also seen that the organizational arrangement and mechanism of NPTEL, with respect to reaching out to a larger audience as well as providing for user preferences and incentives, was better than that of IIT Bombay EduSat network.

5. Concluding observations

A natural conclusion from the above discussion is that technology intervention in education should keep in focus the capabilities of all the actors involved, as well as strive for organisational arrangements and mechanisms that are based on the opportunities and incentives of these actors. This will increase the chances of a fruitful impact of the technology intervention in education.

Application of the analytical framework for innovation systems in the field of education has thrown up an important point that needs to be highlighted. The reader would have noted that the outcome of the technology intervention in both the case studies have not been touched upon. For innovations happening in the educational domain, few innovation practitioners may define success of such a TSIS as improvement in human capital due to the TSIS. Using the case studies above we would like to argue that this is an excessively strict definition to measure the success of the innovation system and should not be used. It is common knowledge that given the wide variability in the understanding ability/quality of absorption among humans, the same amount of tutoring/information will lead to variable outcomes in the quality of human capital for each individual. Thus, this outcome is beyond the control of the TSIS as it is individual specific. Moreover, human capital is a function of time and many parameters, thus isolating the effect of such a TSIS on human capital will not be straightforward. Needless to add, collecting data to measure improvements in human capital due to such interventions will also be a laborious exercise. In the case studies discussed above, what the TSIS's tried to ensure was to use the innovation to help the students and other faculty (present as actors in the TSIS) access quality content. IIT Bombay-EduSat network was not able to reach everybody it intended to, whereas the reach of NPTEL has been much better. Thus, for these TSIS's, success in realistic terms should be measured in terms of their reach and not how effective they have been in improving the human capital. We would like to conclude this paper stating that success of TSIS or technology intervention in the field of education should be measured in terms of its reach.

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